optics

The future of

optics

is at

NASA

Marshall Space Flight Center

Technologies we need to reach the stars are the engines that drive America's future.

***Optics technologies** play a key role in every aspect of our lives: from music to medical research and from telecommunications to transportation. Developing these technologies, however, is an expensive and time-consuming process requiring expertise, equipment, and facilities that are often beyond the reach of many companies and universities.*

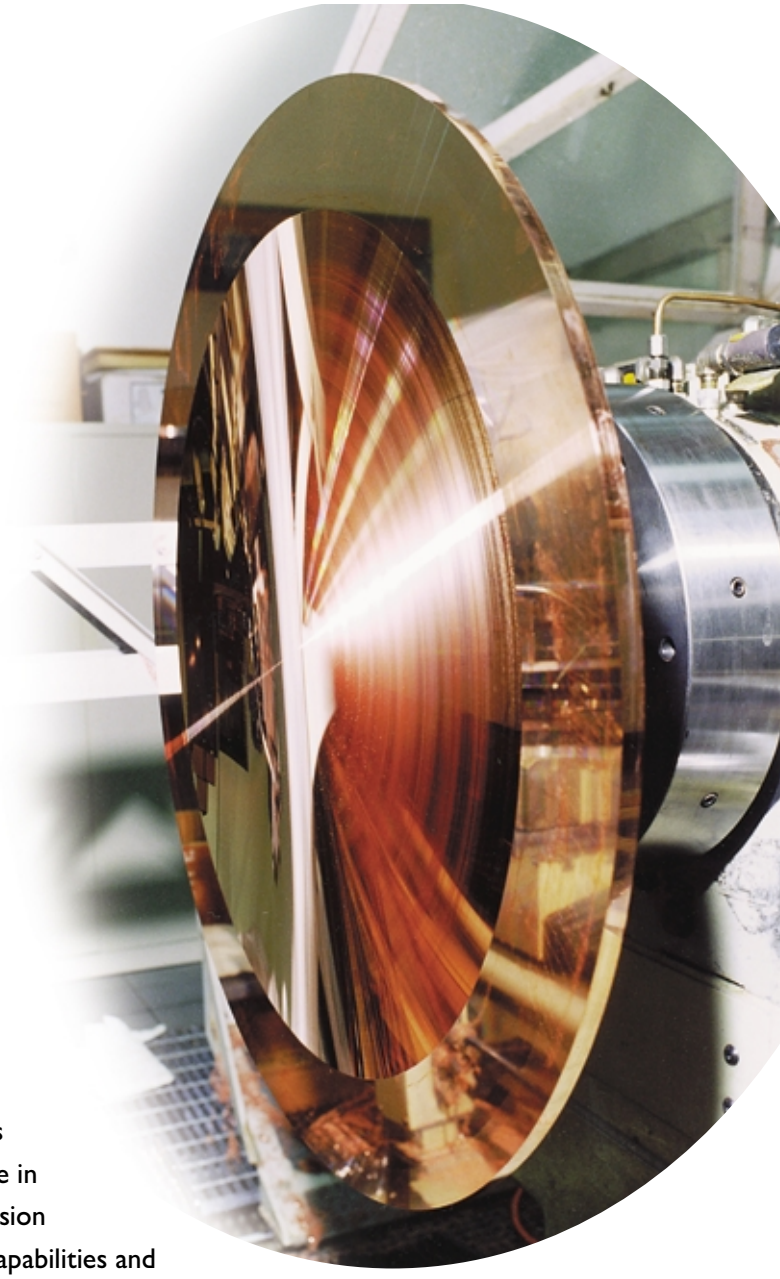
Marshall Space Flight Center leads NASA's space optics manufacturing technology development. We have over 30 years of experience developing sophisticated optical systems for space exploration. These efforts have given us unique expertise in optics design, fabrication, testing, and analysis. Our world-class facilities include a wide range of standard and unique equipment.

These facilities, capabilities, and expertise can be made available for commercial, academic, and other ventures. We invite you to partner with Marshall to develop new optical technologies, learn from our expertise, or benefit from our comprehensive facilities. This information booklet describes our capabilities in the following areas:

- *Design and fabrication*
- *Testing and analysis*

Cooperative Efforts Benefit Marshall and Industry

Industry partnerships with Marshall Space Flight Center not only help businesses be more competitive but also benefit the space program. Reflexite Corporation, which is based in Avon, Connecticut, manufactures fresnel lenses and other microstructured optical products for solar applications and other uses. Wanting to develop a new product line that uses larger lenses, Reflexite partnered with Marshall to use the Moore M40 diamond turning machine. Donated to Marshall by IMO Industries, the Moore M40 is one of the world's largest diamond turning machines and enabled Reflexite to machine lenses larger that its own equipment could supply.



When Marshall began to investigate the use of fresnel lenses in solar thermal propulsion and cosmic ray detection, the partnership was expanded to permit closer collaboration. Reflexite researchers trained Marshall researchers in the complex process involved in high-precision machining of large-aperture fresnel lenses. This arrangement proved to be mutually beneficial, allowing both Reflexite and Marshall to achieve their goals.

"This type of cooperative program bolsters NASA's capabilities while giving industry the tools we need to be more competitive in the marketplace," said Steve Scott, director of Reflexite's Precision Technology Center. This booklet describes the Moore M40's capabilities and other equipment that may benefit commercial, academic, and other researchers.

Marshall's facilities, capabilities, and expertise can benefit designers and manufacturers of optics used in a variety of products:

- Cameras
- Computers
- Inspection devices
- Lasers
- Lenses
- Medical imaging devices
- Microelectronics
- Navigation equipment
- Pollution monitoring equipment
- Property and safety monitoring devices
- Satellites
- Semiconductors
- Telecommunications equipment
- Telescopes
- Video hardware

Design and Fabrication

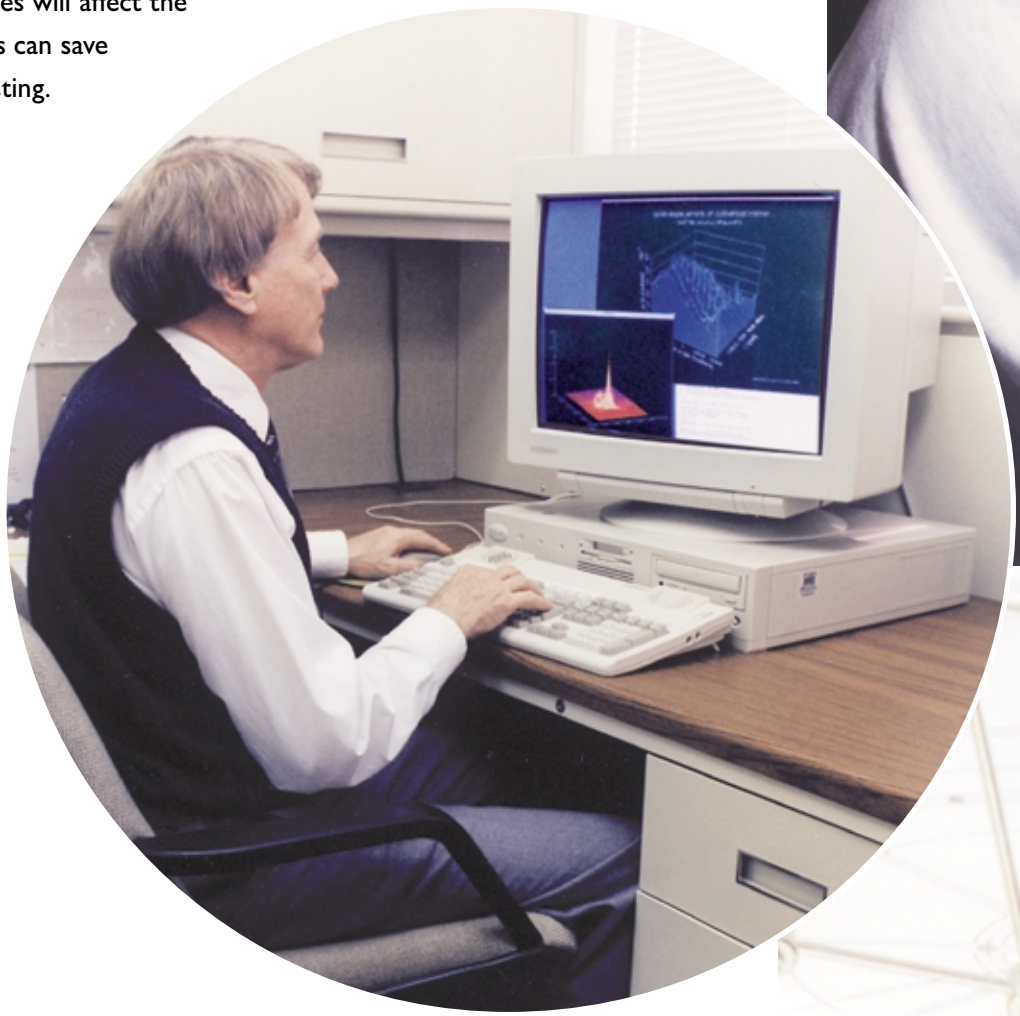
Marshall's experience in developing complex, sophisticated optical systems has provided us with the resources to design and fabricate high-quality devices. Our world-class fabrication facilities contain unique, cutting-edge equipment to manufacture standard and advanced optics in a variety of materials.

Design

The experts at Marshall have designed optical components such as lenses, mirrors, gratings, diffraction elements, prisms, and beam splitters. This wealth of experience, combined with state-of-the-art computer hardware and software, can benefit commercial industries. Companies interested in working with Marshall on new optical and optomechanical designs are encouraged to contact us.

Optical Design

Developing laser radars, spectrometers, telescopes, and other optical systems to meet NASA's mission goals requires extensive design capabilities. Marshall's optical design facility is based on a Sun Microsystems server with 11 workstations. Commercial and custom-programmed software can be used to evaluate how structural, thermal, and dynamic influences will affect the performance of optical components. This can save thousands of dollars in trial-and-error testing.

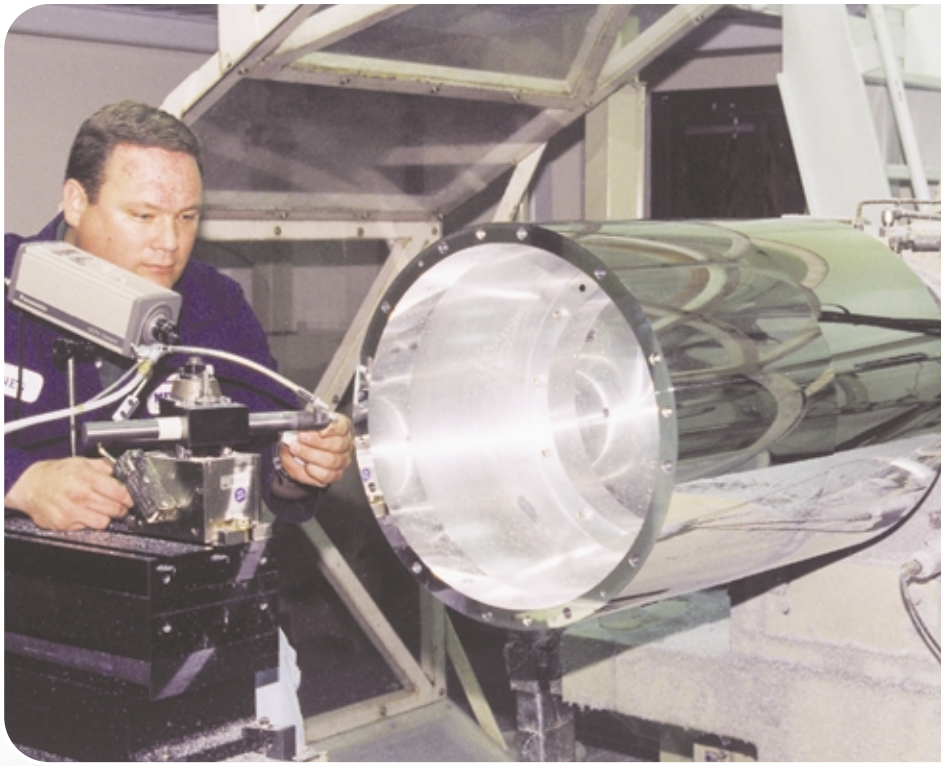


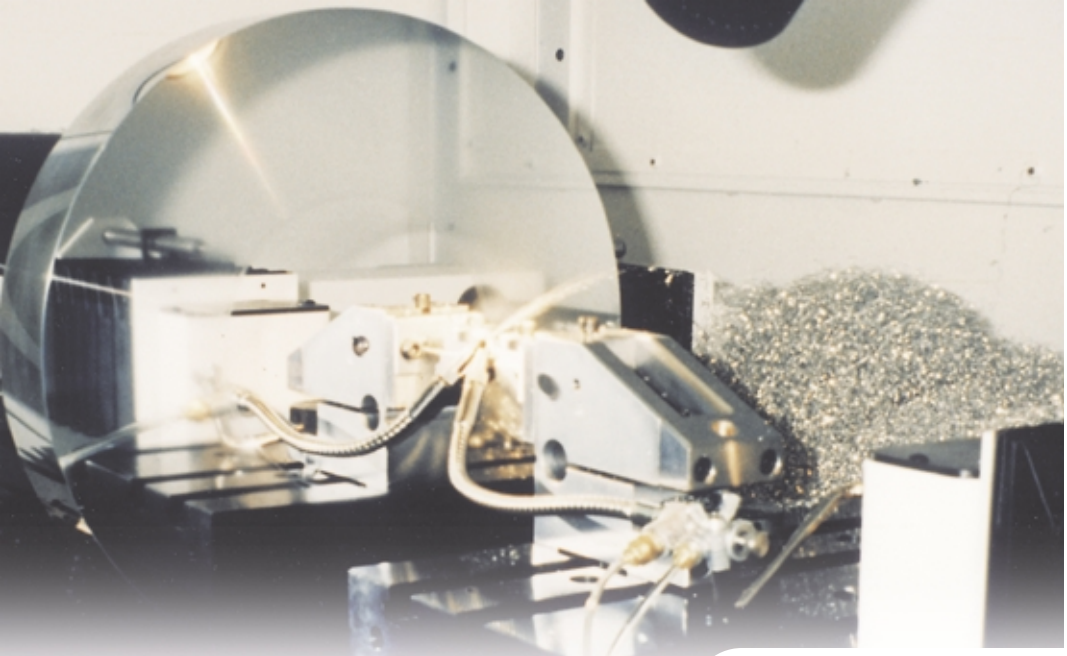
Optomechanical Design

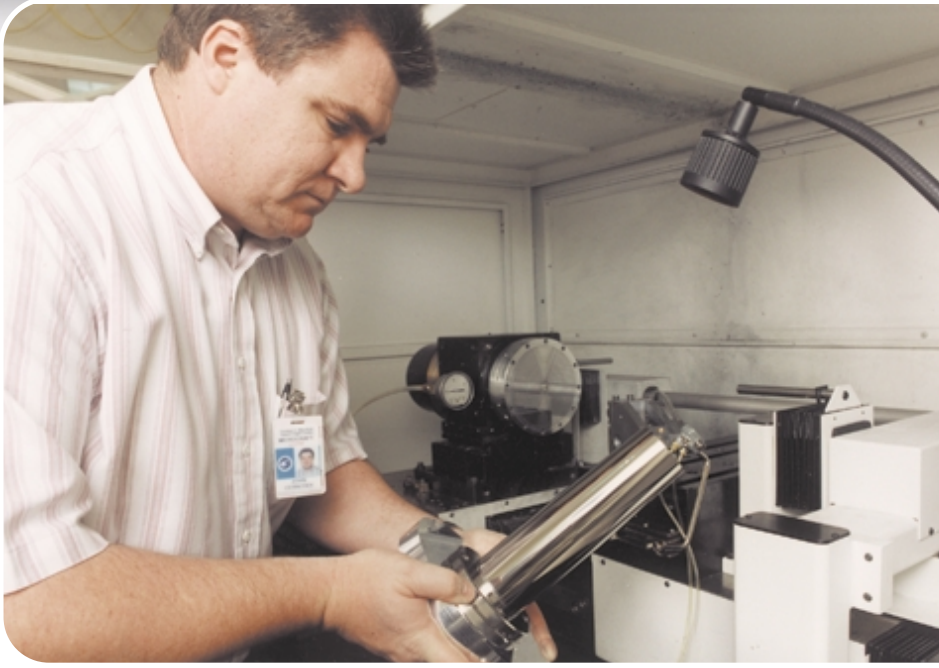
A perfect lens design may be less than perfect in operation if great care is not taken in how it is mechanically mounted. High-quality optical systems therefore also require the involvement of experienced optomechanical designers. Marshall's researchers use five Intergraph workstations to ensure that the opto-mechanical design is compatible with the overall system.

Fabrication

Sophisticated optics require advanced equipment for diamond turning, grinding and polishing, coating, and optomechanical fabrication to produce high-quality components with damage-free subsurfaces. Marshall's extensive collection of equipment can be used to produce standard and advanced optics from a variety of materials.







Diamond Turning

Marshall's capabilities include the largest cylinder diamond turning machine in the world. Marshall also has a machine that is ideal for smaller components. We keep these machines in vibration isolated rooms with precise thermal control. A 5-ton crane can transport raw materials and finished cylinders.

Moore M40 Diamond Turning Machine

- Face-cut pieces: 3 m in diameter
- Cylinders: 1.5 m in diameter and 1 m long
- Surface finish: 200 Å
- 1,500+ kg hydrostatic spindle capacity
- 1.8 m swing with 360° *b*-axis rotation, as well as 1 m of *x*-axis and 0.8 m of *z*-axis travel
- Supplementary spindle for brittle materials
- Integrated interferometer and computer-controlled translation system

Precitech 4200 Diamond Turning Machine

- Face-cut pieces: 0.4 m in diameter
- Cylinders: 0.25 m in diameter and 0.3 m long
- Surface finish: 20 Å

Grinding and Polishing

Marshall's grinding and polishing equipment ranges from conventional spindles to custom-designed polishers. These capabilities allow us to grind precisely and polish a variety of optical devices, including X-ray mirror mandrels.

Equipment

- Precision surface grinder
- Blanchards
- Curve generators
- Lens edging and centering machines
- Plano polishers
- Spindle polishers
- Double-sided planetaries
- Computer-controlled polishers
- Ion figuring system

Coating

Marshall's extensive coating capabilities can be used to design filters and apply highly reflective, high-density films to a variety of materials. Coating films may be dielectric, metallic, or semiconducting and can be multilayered.

Large Aperture Coating Chamber

- Accommodates optics up to 5 m in diameter
- Cryopumps to achieve a vacuum of 10^{-7} torr
- Provides class 10,000 cleanliness

Balzer E-Beam Box Coater

- Accommodates optics up to 0.7 m in diameter
- Provides four-hearth electron beam source
- Automatically monitors for film thickness from 200 nm to 3,200 nm

Magnetron Sputter Coater

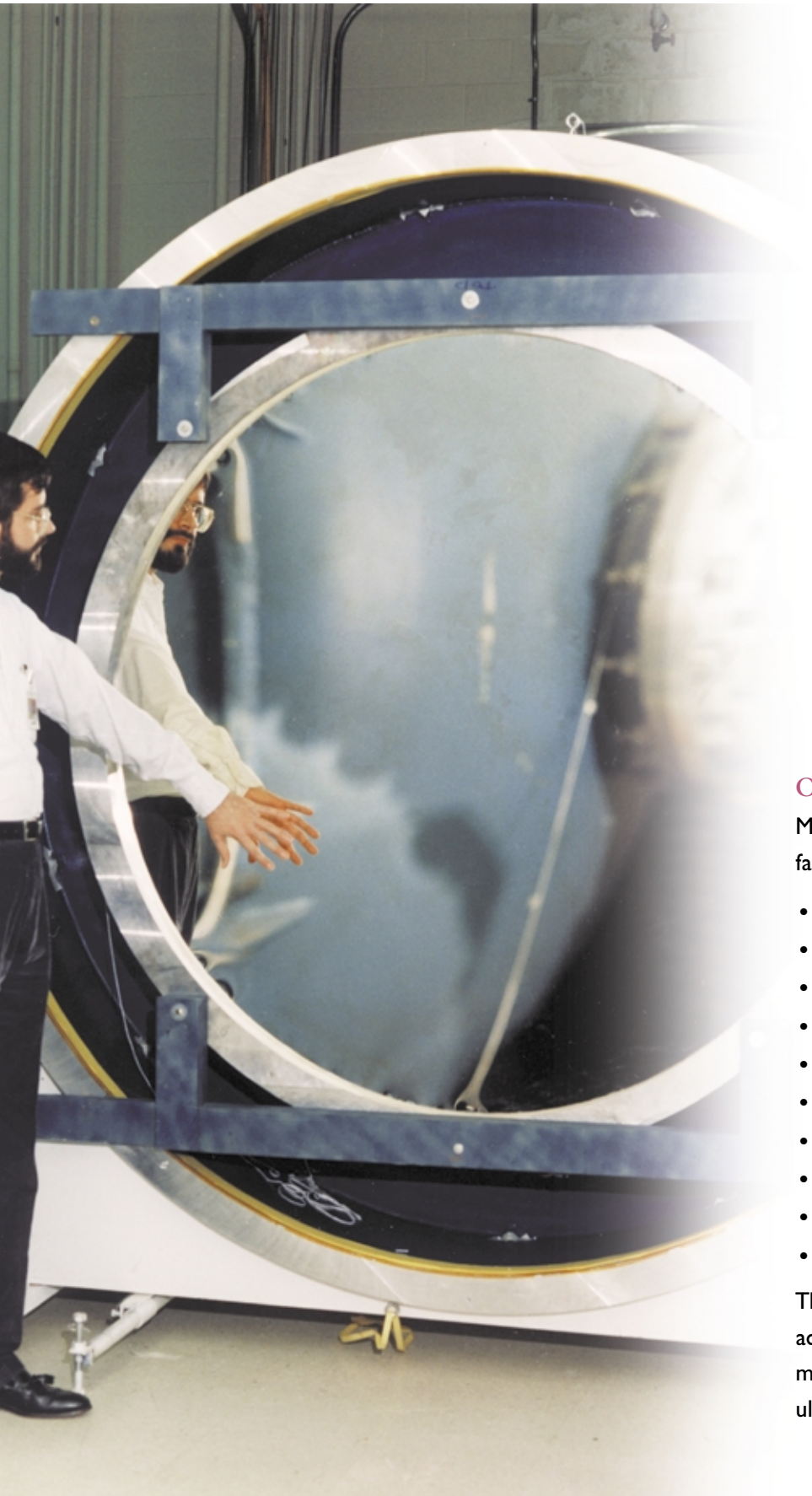
- Accommodates cylindrical optics up to 0.45 m in diameter
- Uses two rotatable-target magnetron sputter sources (75 mm in diameter and 350 mm long)
- Produces uniform, high-density coatings inside small cylindrical X-ray optics

Optomechanical Fabrication

Marshall has acquired a variety of equipment to produce mechanical components, including special-purpose tooling, mounts, and other hardware. The facility includes a computer-controlled lathe, a five-axis computer-controlled milling machine, and other general purpose machines.

Advanced Optics

Marshall leads advanced research on replication, single-point diamond turning, ductile regime grinding, and deterministic ion figuring for optical components. This research is conducted on site and through Marshall-sponsored programs around the world. We also establish collaborative programs with industry, academia, and other government agencies. Whether you are interested in participating in this research or simply want to benefit from the knowledge Marshall has gained, we encourage you to contact us.



Optical Materials

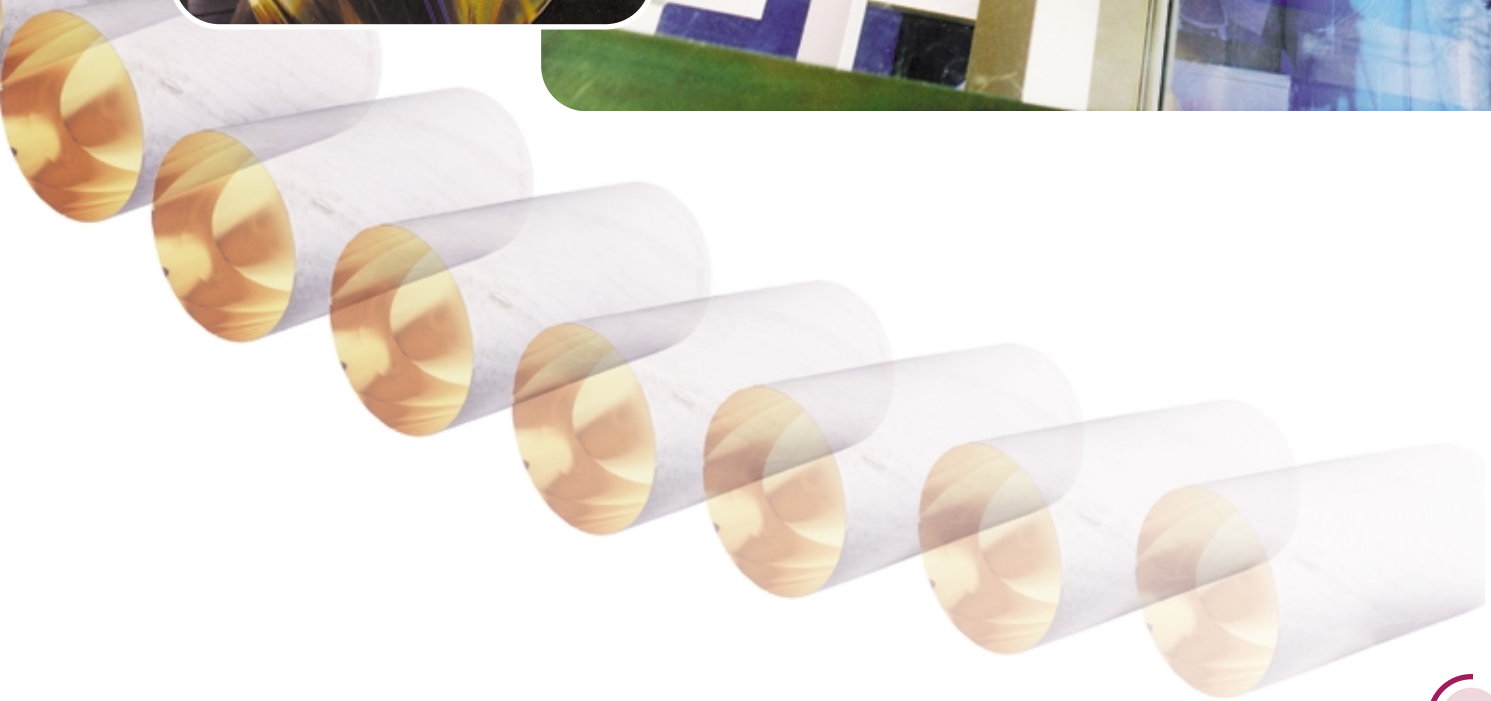
Marshall has the experience and equipment to fabricate optics from a variety of materials:

- Optical glass
- Low-expansion materials
- Silicon and silicon carbide
- Composites and other advanced materials
- Glass ceramics
- Polymers
- Shape-changing materials and memory metals
- Beryllium
- Electroformed nickel
- Siliconized aluminum

These capabilities are ideal for fabricating advanced optics such as lightweight metallized mirrors, composite infrared mirrors, and ultraviolet imager mirrors.

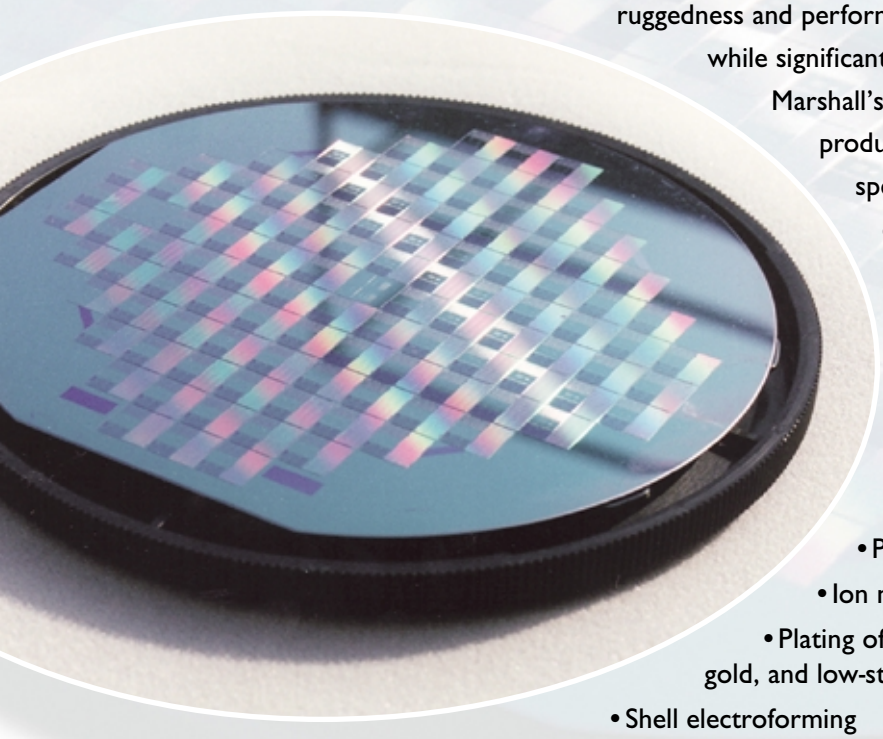
Replication

To reduce the cost of mirror fabrication, Marshall has developed the machinery, techniques, and materials to replicate electro-formed nickel mirrors. We can fabricate precisely shaped mandrels to be used and reused as masters for replicating high-quality mirrors up to 0.5 m in diameter.



Diffractive/Integrated Optics

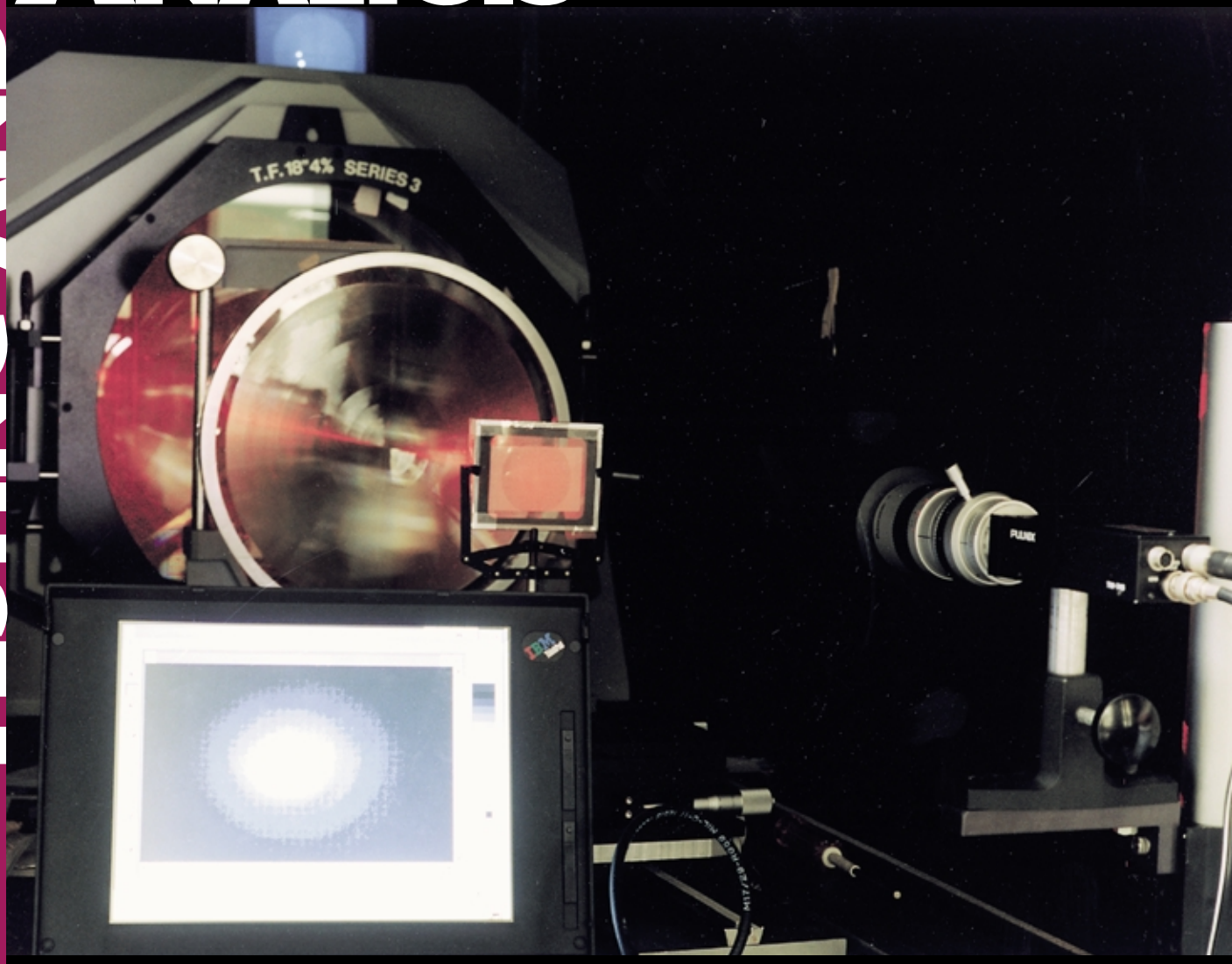
Combining diffractive and geometric optics can improve the ruggedness and performance of optical systems while significantly reducing size and weight. Marshall's laboratories enable this integration to produce antireflective coatings, polarizers, spectrometers, optical interconnections, corrections for diffractive telescope aberrations, and communications technologies.



Capabilities

- Etching and coating
- Direct-write electron beam lithography
- Photolithography
- Ion milling and etching
- Plating of electroless nickel-phosphor, gold, and low-stress electrolytic nickel
- Shell electroforming

Testing and Analysis



The variety of equipment available at Marshall for optical testing and analysis is unparalleled. We have the facilities and expertise needed to evaluate optical materials, verify figure and surface finish, and determine overall optical performance. Companies interested in testing optical components, systems, or subsystems or who are interested in advancing the state of the art in optical testing may find these facilities invaluable.

Optical Metrology

Our comprehensive facilities have all the mechanical and optical metrology tools needed to ensure that optical systems will perform properly.

Surface Morphology Equipment

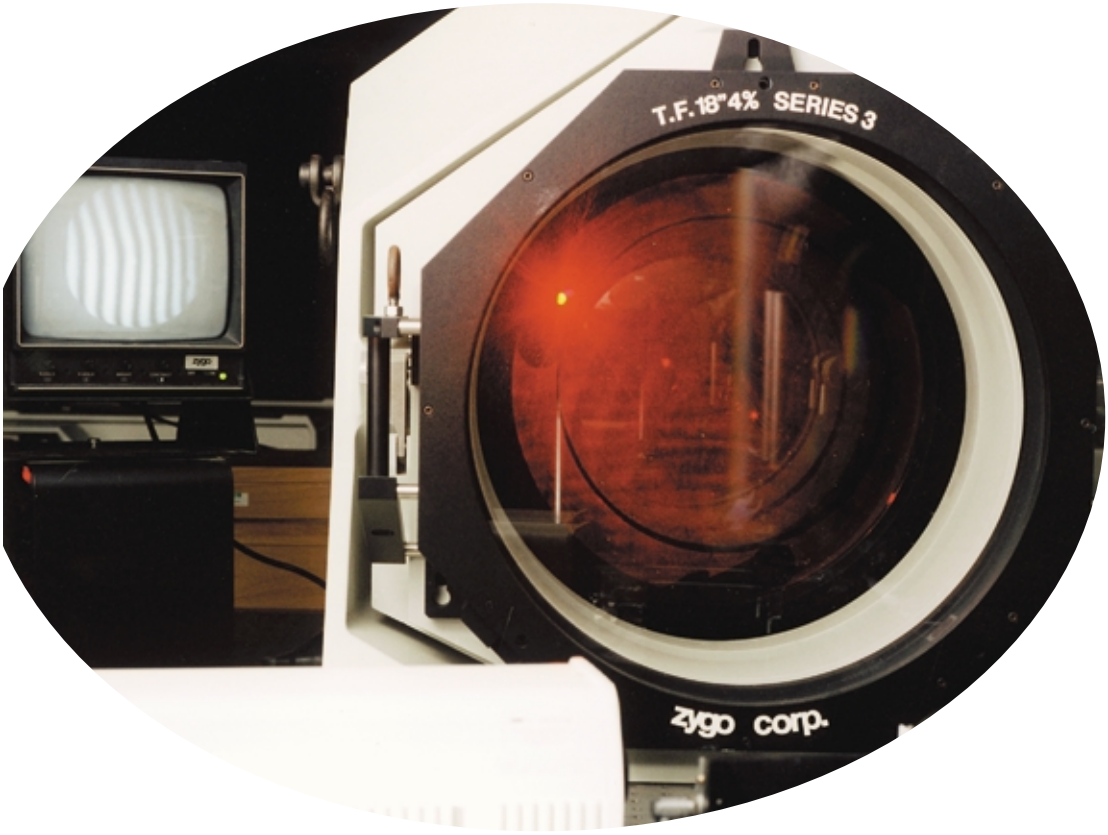
Marshall's various microscopes and profilers can find nanometer-sized surface features on optical surfaces:

- Atomic force microscope
- Scanning tunneling microscope
- Rank-Taylor Hobson nanostep profilometer
- Wyko profilometer
- Nomarski phase contrast microscope
- Optical heterodyne profilometer
- Bidirectional reflectance distribution function (BRDF) systems

Dimensional Metrology Equipment

Marshall has a variety of equipment to verify the dimensional accuracy of optical components:

- Zeiss coordinate measuring machine
- Long-trace profilometer
- Bauer profilometer
- Nanostep profilometer
- Talysurf profilometer
- Zygo interferometer system (includes 4-inch, 18-inch, and 32-inch expanders)



Other Metrology Equipment

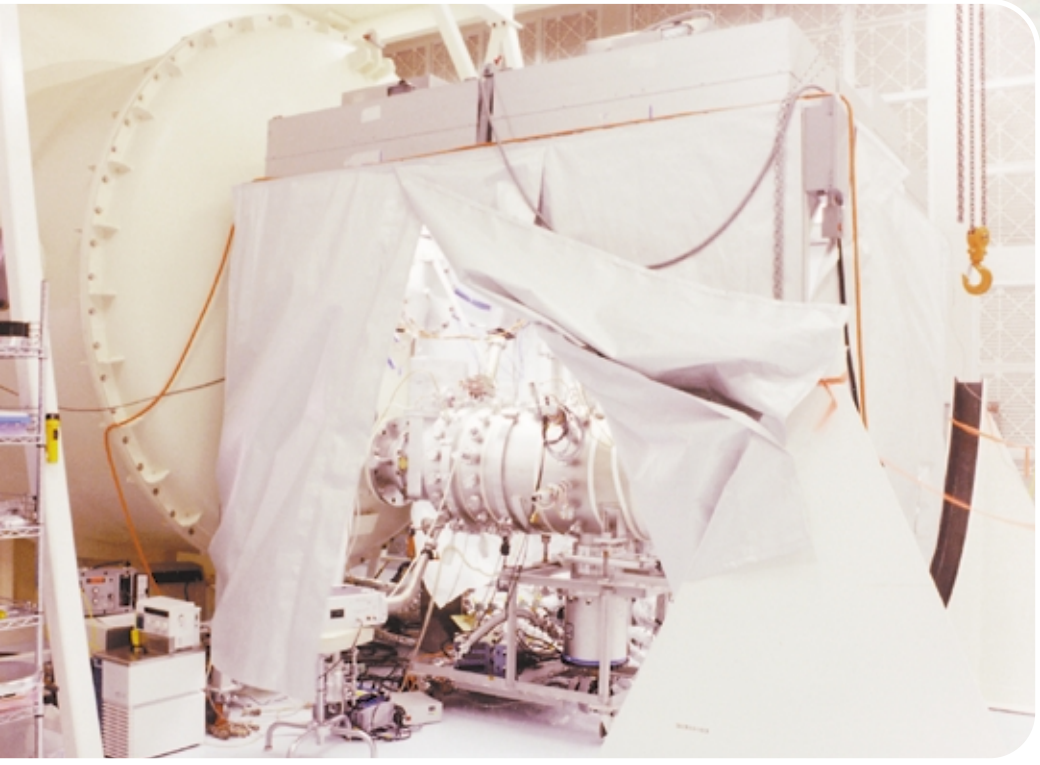
- 12-inch Goetz autocollimator
- 16-inch diffraction-limited collimator
- Precision optical benches
- Automated stress analyzer
- Laboratory microscopes

Optical Testing

To ensure that telescopes and other optical systems will perform properly on space missions, Marshall has several facilities that characterize and calibrate optics. Please contact us for more information on the availability of these facilities.

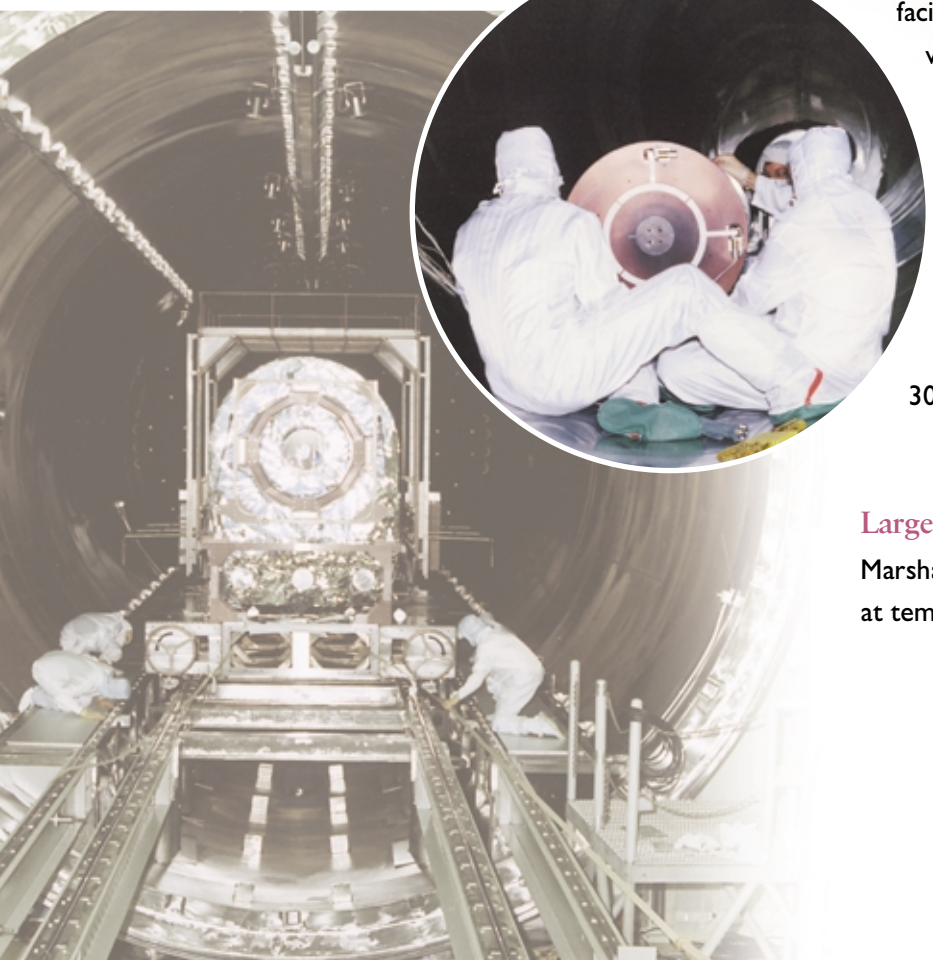
Straylight Test Facility

This unique facility is designed to evaluate telescope baffle systems, measuring straylight radiation reflection ratios of 10^{-15}. Consisting of a 3-m x 12-m chamber attached to a 100-m long tunnel, the facility can achieve a vacuum of 10^{-7} torr, simulating space conditions. Class 10,000 clean room conditions also can be achieved.



X-Ray Mirror Calibration

Marshall offers a unique facility for testing and calibrating X-ray optics and telescopes up to 1.4 m in diameter. This facility uses a variety of generators, filters, and monochrometers to provide a collimated X-ray beam over a 518-m optical path—making it the largest such facility in the world. Test energies range from 0.1 to 10 keV. X-ray detectors include a multi-channel plate camera, thin-window proportional counters, and solid-state detectors. Larger space optics can be tested in the 6-m x 18-m facility, which offers precision thermal controls from 30 to 350 K and a class 1,000 clean room.

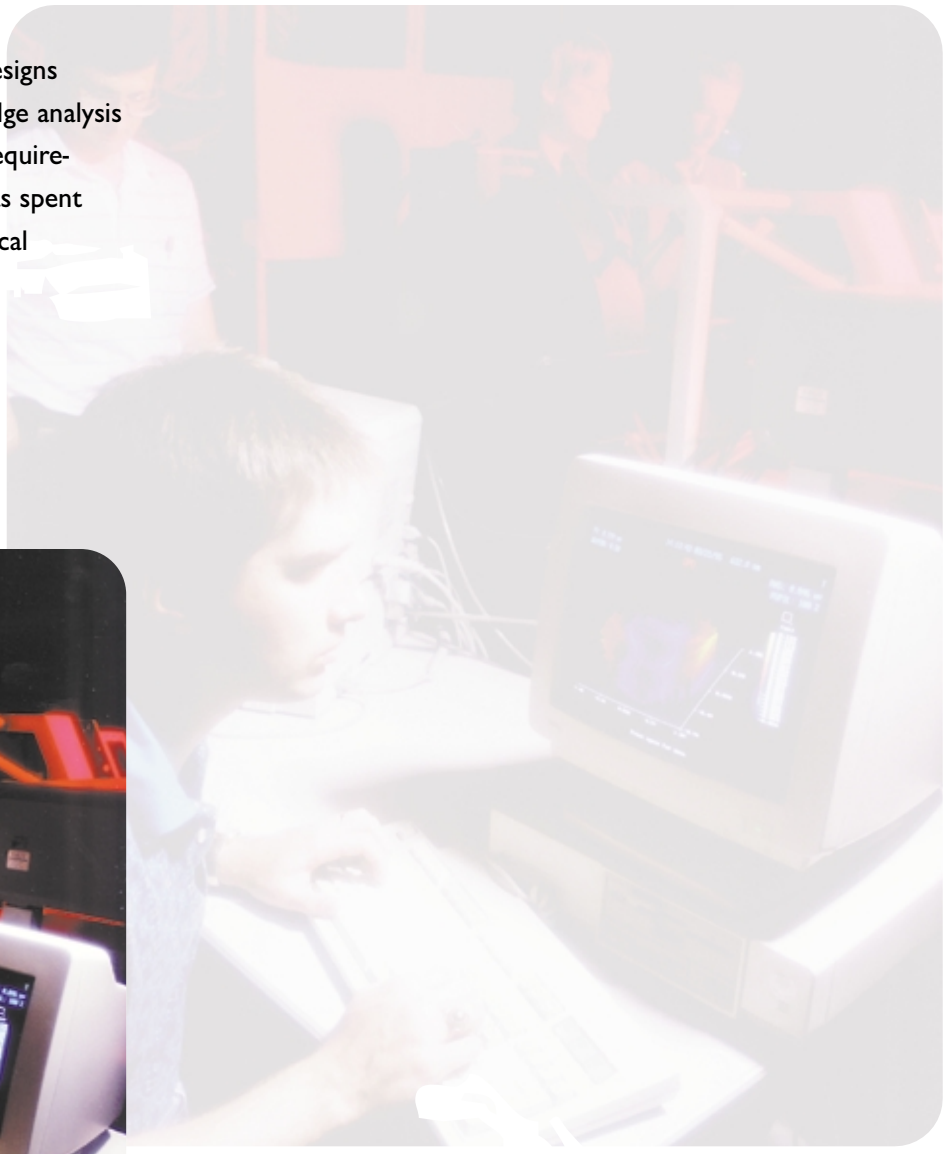


Large Aperture Cryogenic Mirror Testing

Marshall can test mirrors up to 2 m in diameter at temperatures as low as 30 K.

Optical Analysis

Excellent optical and mechanical designs must be accompanied by cutting-edge analysis to predict whether performance requirements will be achieved. Marshall has spent years perfecting a variety of analytical techniques to determine telescope performance.



Analytical Techniques

- Error budgeting
- System modeling
- Performance analysis
- Thermal analysis
- Stress analysis
- Materials selection and analysis
- Metrology
- As-built predictions
- Ground-based and space-based interactions

Learn from Marshall's Optics Experts

Researchers in Marshall's optics laboratories can provide training to industry, academic, and government researchers and technicians interested in improving their optics capabilities. Our experienced personnel can provide unique insight into the complex techniques and technologies involved in designing, fabricating, testing, and analyzing high-quality optics:

- Optical and optomechanical design
- Diamond turning
- Grinding and polishing
- Coating
- Metrology
- Optical performance testing
- Optical analysis

For more information on training opportunities at Marshall, contact the Technology Transfer Office.

Technology Transfer at Marshall

This information package has been assembled as part of NASA Marshall Space Flight Center's technology transfer program. The primary goal of the technology transfer process at Marshall is to encourage broader utilization of Marshall-developed technologies and unique combination of facilities in the U.S. industrial communities.

We invite you to contact Marshall to discuss possible partnership opportunities and availability of facilities.

NASA Marshall Space Flight Center
Technology Transfer Office
Mail Code: CD30
Huntsville, AL 35812

Telephone: *(256) 961-4010*
Fax: *(256) 544-3151*
E-mail: *tto.optics@msfc.nasa.gov*
Internet: *www.nasasolutions.com*

NP-1999-6-66-MSFC